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Yale University
New Haven, Connecticut

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Navigation in Mine Hunting

by

E. L. Woodside

Technical Memorandum, No. 37
16 August 1956

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ABSTRACT

~~This Memorandum describes briefly~~ the problems of navigation involved in general mine hunting operations are described. It is assumed that very few, if any, vessels engaged in mine hunting (as distinguished from mine-sweeping) will be equipped with sophisticated navigational equipment, including plotting facilities. A "Position Plotter" is described which is designed to simplify and expedite the plotting of observed navigational bearings. This enables a vessel to determine its own progress, and the direction and distance to a plotted "destination," even though it is equipped with minimum navigational facilities.

~~The Memorandum~~ then ~~discusses and recommends~~ a system of cooperative effort on the part of the mine-hunting boat and shore observation stations, is discussed whereby maximum attainable accuracy may be achieved with a minimum of overlapping of activities between boat and shore stations. The boat would be self reliant and able to approach its destination with a fair degree of accuracy, and could call upon the shore station only for final refinements of attainable accuracy.

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NAVIGATION IN MINE HUNTING

The General Problem

A great deal of time and effort have been expended toward devising ways and means of determining accurately the position of enemy mines as they may be laid. Could the position of each mine be determined, that position could be definitely marked - like any other obstruction to navigation -, and avoided until the mine could be neutralized.

At the present time, there is no known method for determining the launched positions of individual mines as they are placed by underwater means, - such as from a submarine, submerged hatches or wells in a cargo vessel, or carried under the keel of a small vessel (e.g. mines laid by junks in Korean waters). For these cases, elaborate detection systems have been devised for tracking the progress of suspicious vessels. These systems comprise combinations of magnetic loops, heralds, sono-buoys, radar, visual watching, photography, infra-red, etc. The best that can now be done to counter a mine threat from these means, is to determine the progress of the suspicious vessel; then, using the determined plot of such vessel, sweep along the same line for moored mines and, using specially equipped boats, hunt along the same line for bottom "influence-type" mines.

In the case of mines launched from above the surface of the water - as from the deck of a surface mine-layer, or dropped from an airplane - means have been devised (and are steadily being improved as to sensi-

tivity and reliability,) for determining the actual location of each mine as it enters the water. By such means information is obtained to enable each mine to be marked for avoidance and neutralization. This means include ~~visual~~ observation, radar, white-light and infra-red photography.

In any case, the accuracy of determination and plotting of the observed data will greatly affect the success of the operation of neutralizing the threat of mines laid. To this end, a great deal of effort has been made toward improving the accuracy and reliability of each part of the system involved in the collection and recording of data. This includes studies of methods to improve the navigation of the mine-hunting vessels, to enable them more accurately to proceed to a position determined from observations of the mine or mine-laying craft.

The problems associated with "mine watching", and detailed discussion of methods of solution of such problems have been discussed in the following papers of personnel from the Laboratory of Marine Physics, Yale:

TR No. 23, by Carl W. Miller, dealing with Photographic problems.

TR No. 32, by V. Withington, "Location and Navigation in Mine Countermeasures Operations".

TR No. 33, by W. R. Guild, dealing with applications of Radar to the problem.

These reports indicate the degree of accuracy with which the point of entry of an air-dropped mine may be determined. The latter two also

discuss the problem of directing a mine-recovery vessel to a point previously determined as the entry point of a dropped mine. This was successfully accomplished by "piloting" from a shore position, using radio voice communication to the steersman of the boat.

This paper will devote itself primarily to the navigation problem of the mine-hunting vessel.

When nothing whatever is known of an enemy mine-laying operation, and mine clearance operations are based solely upon a precautionary assumption of some enemy mining activity, it is obviously impractical to attempt a thorough clearance of the entire harbor and harbor approach area. The cost of such in time and energy would be prohibitive. Consequently, attention of the defense forces is concentrated on the channel leading into the harbor, and on such relatively small anchorage area as is vital to the operation of the harbor. Even here, the mine clearance vessel must operate along a definite, pre-arranged and charted course.

The Navigation Problem

In the case of mine-sweepers, they are usually vessels of sufficient size to warrant their being supplied with very modern, highly accurate navigational equipment. Such equipment would include a gyroscopic compass, with suitably located repeaters, azimuth circles, charts and a comfortable chart table; all for use of conventional navigational methods. Some, particularly the larger vessels, will probably also carry radar and other electronic navigational equip-

ment, for example "Shoran", etc. These vessels should be capable of determining their position at any time with an accuracy nearly equal to that of equipment for observing mine-placement data. During periods of reduced visibility, (fog, rain or falling snow) the electronic equipment must be relied upon heavily for determining position. While "course and distance made good" from a previous "fix" will supply approximate information as to position, this is by no means accurate enough for mine-sweeping or mine-hunting work. During fair to good visibility conditions, position can be established by the conventional means of observing and plotting the bearings of three well-charted navigational aids ashore. Since bearings can be observed accurate to ½ degree of arc, and the bearing line can be plotted accurately, the bearing line of position can be relied upon for accuracy of $^1/_{114.6}$ x range.

But even the simple method of determining a ship's position by plotting observed bearings of three fixed navigational aids can be laborious, time-consuming and susceptible to errors. This was brought home to the writer when, as the Navigator of a Light Cruiser, he was frequently confronted with the problem of bringing the ship accurately to anchor in a definitely charted anchorage, where the anchor must be dropped within a charted circle about 30 yards in diameter. Delays in determining the ship's position during the approach were largely due to the time involved in plotting the observed bearings. To reduce this plotting time, a "Position Plotter" was contrived, consisting of a set of three separate protractors of transparent plastic.

The "Position-Plotter"

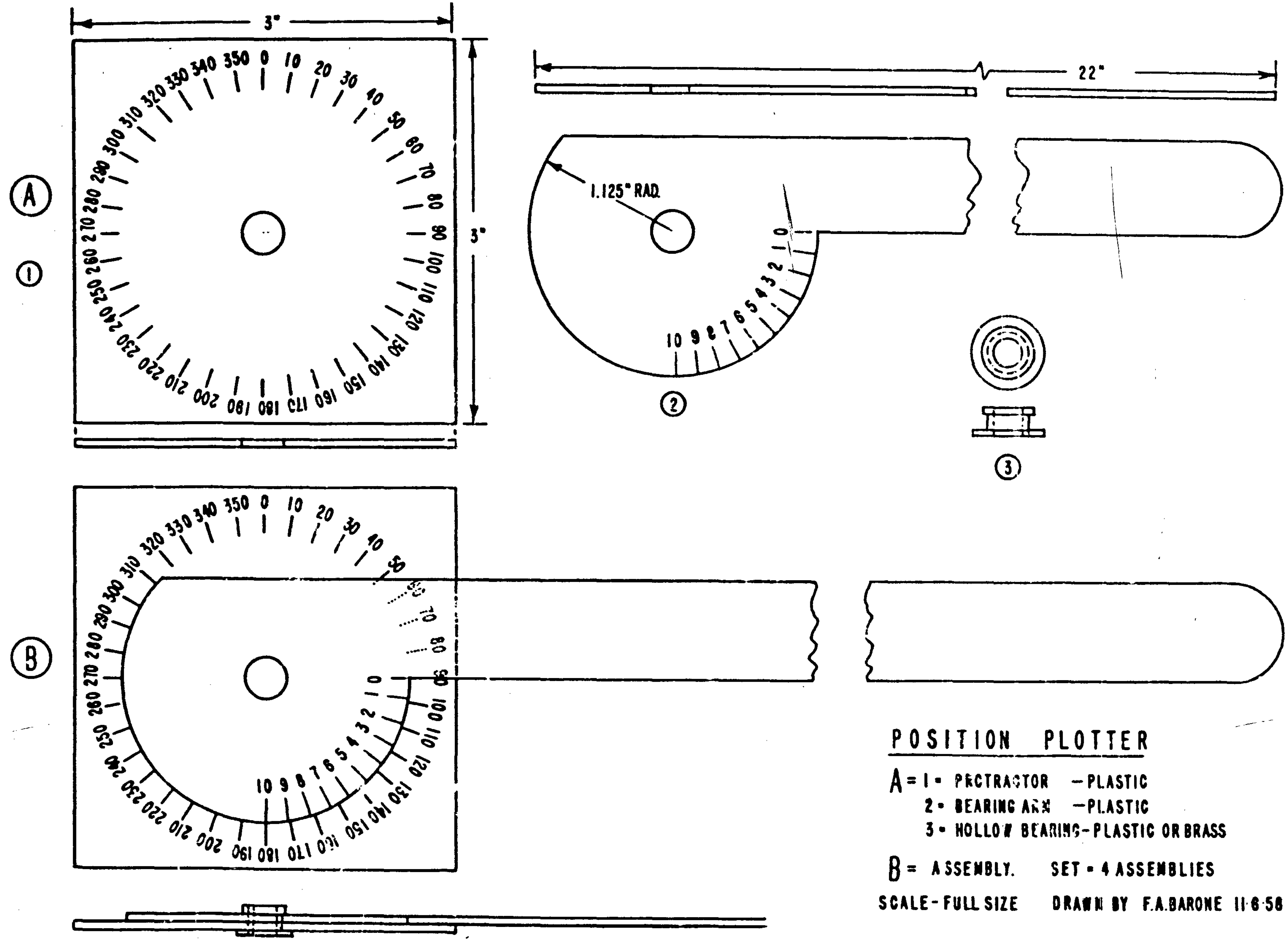
Each Protractor - which is constructed as small as practicable conducive to the required accuracy - is scribed to read from 0 to 360 degrees. A long (18" to 24") "plotting arm" of similar plastic material is pivoted to the protractor so that the "drawing edge" of the arm - extended - passes accurately through the center of the protractor. The protractor and arm are fastened together by means of an accurately-centered, hollow bearing. As the arm is pivoted to various bearing settings, the extension of the drawing edge must always pass through the center of the protractor. The opening through the hollow bearing is about ¼ inch in diameter: this is large enough to permit recognition (when looking through it onto the chart) of the charted position of the object being observed, and yet small enough to facilitate centering the protractor over that point.

While three of these units constitute a "set", it is well to have on hand a fourth similar unit, to be used in lieu of parallel rulers or for other purposes to be discussed later.

Operational Use of "Plotter"

The operational procedure is as follows:--

First, let us assume that the vessel is equipped with a gyro-compass, with repeaters suitably mounted to command a good view in all horizontal directions, and each equipped with an azimuth circle. Also there should be direct communication, - telephone or voice-tube -



POSITION PLOTTER

A = 1 - PRCTRACTOR — PLASTIC
2 - BEARING ARM — PLASTIC
3 - HOLLOW BEARING - PLASTIC OR BRASS

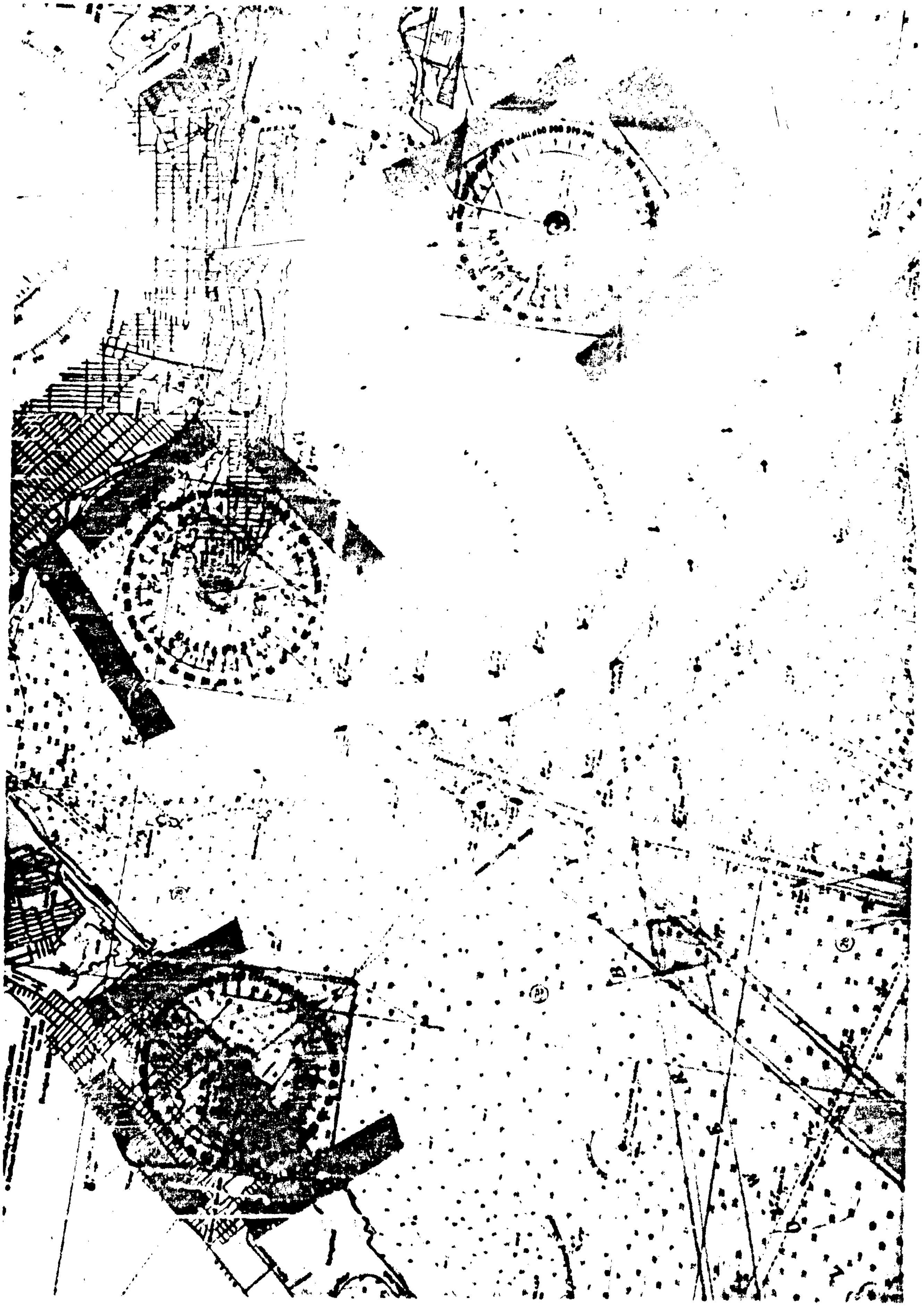
B = ASSEMBLY. SET - 4 ASSEMBLIES

SCALE - FULL SIZE DRAWN BY F.A.BARONE 11-6-58

between the navigator at the chart-table and each azimuth-circle observer.

The selected navigational chart is laid out flat on and secured to the chart table. The navigator selects three fixed navigational aids whose positions are clearly plotted on the chart. These may be such objects as light-houses, beacons, smoke stacks, church-steeples, prominent tall buildings, radio towers, and so on. At night we are restricted to the use of fixed navigational lights as targets. In making his selection he should be guided by such considerations as (1) relative position to give good bearing angle cuts, (2) visibility conditions, (3) ease of distinguishing the target, (4) probable effect on relative positions due to anticipated maneuvers of own ship, (5) ranges to targets, and (6) linear distance between charted positions, which should not be less than the width of each protractor unit. Having selected his "targets", he should assign them to his bearing-observer assistants, who should also be carefully instructed to insure against confusion of targets, and to insure uniformity and promptness in reporting their observations.

A protractor unit is then secured, properly oriented and carefully centered over each of the charted positions of the selected targets. To orient the protractor, center it carefully over the target, then holding it thus centered, swing the plotting arm so that its reading edge passes through the center of the nearest compass rose printed on the chart. Read the true bearing indicated on the compass rose where the plotting arm intersects the scale in that quadrant <u>toward</u> the target.



Now holding the bearing arm firmly flat on the chart, rotate the protractor until its reading is the same as shown on the compass rose (the bearing of the target from the center of the compass rose.) Secure the protractor in this position, - thumb tacks or strips of draftman's tape.

In like manner position a protractor unit over each target.

Should some unforeseen circumstance render a selected target unsuitable, such as local smoke conditions etc, an alternate target can be selected, and the protractor shifted to this new target in a matter of about thirty seconds of time.

To determine the ship's position at any instant, the navigator gives a pre-arranged signal, whereupon the observers note and report the bearings of their assigned targets, - as nearly simultaneously as practicable. As the bearings are received, (and recorded), the navigator moves the protractor arms to the corresponding readings. Where the reading-edges of the three arms intersect is the position of the ship at the time of observations.

<u>Theoretically</u>, if the compass is correct and no errors made in observing the bearings or in setting the arms, two bearings would be sufficient. Also, theoretically the three arms should intersect in a point. <u>Practically</u>, they seldom do. Instead they usually form a small triangle, and for this reason it is good practice, when setting a bearing arm, to pencil a light line on the chart to mark the edge of the arm; then move the arm to one side while the reading edges of the other

arms are similarly marked. A small triangle thus formed is tolerated, and the most probable position of the ship is assumed to be the center of this triangle.

Should the triangle be of such size that the bearing of any target from the center of the triangle differs from the plotted bearing by more than one degree, the triangle is intolerably large, and indicates the presence of an unacceptable error. A new set of bearings should be observed and plotted. If this plot produces a small triangle, the error of the preceding plot may be considered as transient, and the data may be discarded. If successive plots consistently give large triangles, a permanent error is indicated, and its source should at once be investigated. It is known that an error can creep into the indications of the gyro-compass when a radical change in speed of the ship is made, until the speed-setting compensator takes effect. Such an error of the compass would be indicated by an enlarged triangle plot in which all three bearing lines are offset from the center by about the same amount, and in the same direction. In this case, all subsequent bearings should be corrected for the compass error, by applying the offset angle noted. The navigator, when plotting, should also exercise care to allow for the advance of the ship between bearing observations that are not made simultaneously: (the ship, at 15 knots, will advance 41.7 yards in 5 seconds time.)

<u>Modification</u>. The above discussion deals with a vessel's method of determining its own chart position at any time, when the vessel is equipped with a gyro-compass. Many boats used in connection with har-

bor defense, particularly mi.e-hunting boats and boats used by underwater demolition teams, are not so equipped. They must rely solely upon magnetic compasses. However, for self determination of position, the boat must have a reliable compass and at least one good azimuth circle for taking bearings. If the compass is so mounted that bearings cannot be taken across it, then a pelorus must be mounted and used to observe relative bearings.

The method of plotting is basically the same as described above, but made more difficult by the following requirements: each time a set of bearings is taken, the heading of the boat by compass must also be noted and recorded. The observed bearings being "relative", the compass heading is added to each to give the "compass bearing" of each target. Then the correction for "deviation" on that heading is applied, to give the "magnetic bearing" of each target. The correction for "variation" is applied when laying out the chart, merely by orienting the protractors according to the "Magnetic Compass Rose" (printed on the chart) instead of the "True" compass rose. The magnetic bearings having thus been computed, and the protractors having been set to magnetic references, the plotting arms are placed according to the magnetic bearings, and their intersection will indicate on the chart the boat's position at the time of observations.

Course And Distance To Destination

Knowledge of the vessel's present position is of great importance to the pilot, but of equal importance and of greater interest is the

information as to course and distance to destination. If the destination be a dock or a mooring buoy, the determination of this information is a very ~~simple~~ matter. In many cases, however, the "destination" may be an assigned anchorage position, or a turning point of a channel, an unmarked spot on the broad surface of water but whose location is indicated on the chart.

Here the fourth (or "spare") protractor comes in handy, in lieu of parallel rulers. Merely center the protractor over the plotted "present position" of the vessel, then orient it as follows: hold the protractor firmly in its centered position and swing the plotting arm to pass through the center of the nearest compass rose printed on the chart. Note the reading (true or magnetic, as desired) under the arm in the quadrant <u>away</u> from the protractor. Now, holding the plotting arm firmly in this position, rotate the protractor until it shows the same reading. The protractor is now oriented to true or magnetic north. Then, holding the protractor firmly against the chart to prevent disturbing its orientation, swing the plotting arm to pass through the charted position of destination, and read the protractor scale. This is the direction (true or magnetic) of the destination from the present position. The course to be steered will, naturally, depend upon shipping, shoals, or other obstructions to be avoided, and upon the effects of currents and wind.

The distance can be stepped off along this direction line. It is convenient to mark the plotting arm with a scale corresponding to the scale of the chart. This is easily done by pressing a narrow strip of

ordinary adhesive tape on the plotting arm, and marking the scale on this, to show distances from the center of the protractor. Then the direction to destination and distance to destination can be shown in one operation.

Another usefulness for the fourth, or loose, protractor develops occasionally when it is desired to observe the bearing of the tangent to a point of land. This situation develops occasionally when cruising well outside a harbor, and when fixed navigational aids are limited in number. Since the bearing line is not tangent to the land at a fixed point for several bearings, the protractor cannot be fastened to one position. The point of tangency for the observed bearing can be closely estimated, and the protractor can be temporarily centered and oriented over this point, (in the same manner as for a fixed navigational aid) and the plotting arm set to the observed bearing, and marked, holding the protractor by hand in its oriented position, during the plotting.

We have discussed a simple navigational method for a vessel's self-determination of its own charted position at any time. The equipment required is very inexpensive, and readily available. It is economical in man-power required, easy to operate, and rapid. It does have two serious limitations: it requires fair to good visibility, (including light visibility at night for using navigational lights); and, in practice, bearings are usually limited to an accuracy of one degree of arc, (although under exceptional good conditions readings can be taken to one-half degree.) With this in mind, it is customary to consider the probable position as being somewhere within a circle whose

diameter is 1/57.3 x the range to the most distant target observed.

Shore-Based Observations

In low visibility (fog, mist, snow) the principal present method of determining a vessel's position involves the use of radar - preferably shore mounted. The problem involves determination of the bearing and distance of the vessel from the radar's known position. This information may be communicated by radio directly to the vessel where plotting could be done. Or, the information could be plotted at a shore based plotting station and the result communicated to the vessel. (the usual "walkie-talkie" is very useful for this communication phase.) This can be done very rapidly, and with considerable accuracy.

Under conditions of fair to good visibility, the vessel's position can be determined with much greater accuracy by means of triangulation observations from well established observation positions on shore. At least two (and preferably three or more) stations should be set up on shore, separated by an accurately determined distance - "base line" - of such length that the angle subtended by this base line, at any probable position of the vessel will be at least 20 degrees of arc. Each station should be equipped with a theodolite or alidade accurately oriented to true north, or on an adjacent station. There should be rapid communication (telephone or radio) between the stations, and radio (voice) communication between the master station and the vessel observed. Since the surveying instruments mounted at each station are capable of being read to minutes of arc, practically, the degree of accuracy is

dependent entirely on the scale of the chart used and the skill of the plotting personnel.

The use of shore based observation stations is necessary at all times to direct to a predetermined position, or along a predetermined course line, a boat that is not equipped with any compass or plotting equipment. This situation may sometimes obtain. But in general, their primary task should be one of surveillance of the area, to plot the location of individual mine splashes when and if they occur, to plot the progress of any suspected craft capable of laying mines, and to assist in piloting friendly vessels to avoid mines or other known underwater dangers. The stations are expensive and difficult to install, and require constant alert personnel for operation. They should not, as a rule, be diverted from their primary tasks in order to guide mine-hunting boats except when refinements of accuracy beyond the capabilities of such boats is required.

Recommended Cooperative Procedure

Operational economy would seem to indicate a procedure somewhat as follows:- Normally, the shore observation stations are engaged on their primary activities as outlined above. Suppose that they track the path of a vessel suspected of mine laying, but observe no individual activity to indicate the actual laying of a mine. The HDCC makes overlays of this plot, giving one copy to the Officer in Charge of sweeping operations. He plots the line on his navigational chart, and conducts a sweeping operation along that line, to remove any moored mines that may

have been laid. The navigation procedure described above should provide ample accuracy for this operation.

Another copy of the plotted track is given to each sonar-equipped mine-hunting boat following the sweepers, searching for influence mines on the bottom. Again, the above-described navigation method will enable the boat to follow the plotted line with an acceptable degree of accuracy. When, however, the sonar equipment gives indication of the presence of a mine-like object on the bottom, the boat should immediately lie to and call upon the shore observation stations for a more accurate determination of the boat's position. At the same time such observations are being taken, the boat should record the bearing and distance to its target, and place a marker buoy to mark the position of the boat as a reference. The mine-removal team will later use this information for locating and neutralizing the mine.

Now let us suppose that the shore observation stations have noted and plotted the position of the splash of an air dropped mine. The equipment avialable should enable the position to be plotted with a high degree of accuracy - probably of the order of 20 yards in a range of 2000 yards. (The probable horizontal deflection of the mine as it travels downward through the water can be expected to exceed this figure by a factor of 2 or 3.) This accurate plot of the probable position of the mine is supplied to the mine disposal unit. The vessel carrying the unit should ~~be able~~ to proceed to the plotted position, by its own navigation. When approximately in position it could call on the shore stations for a more accurate fix, and, being guided by this refinement,

should be able to minimize the time required for locating the mine.

It is to be noted that the navigation here discussed is not limited to daylight hours, but can also be used at night if good fixed navigational lights can be used as targets.

The cooperative system of operation here described will permit the most economical and efficient employment of the equipment and personnel engaged in this phase of Harbor Defense activity. The Harbor Defense forces afloat should be self-reliant with respect to navigation up to the point in time and space where refinements in accuracy are required beyond ~~the~~ capabilities of their own equipment. Only at these short periods will they require the diversion of the shore observation stations from the task of spotting mines, tracking suspicious craft, and assisting in the safe navigation of friendly vessels through cleared channels.

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